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space station systems analysis study

(NASA-CR-179010) DEVELOPMENT PLAN FOR SPACE MANUFACTURING OF HIGH COERCIVE STRENGTH MAGNETS (Grumman Data Systems Corp.) 25 p

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GRUMMAN

DEVELOPMENT PLAN FOR SPACE MANUFACTURING OF HIGH COERCIVE STRENGTH MAGNETS

CONTRACT NO. NAS8-31993

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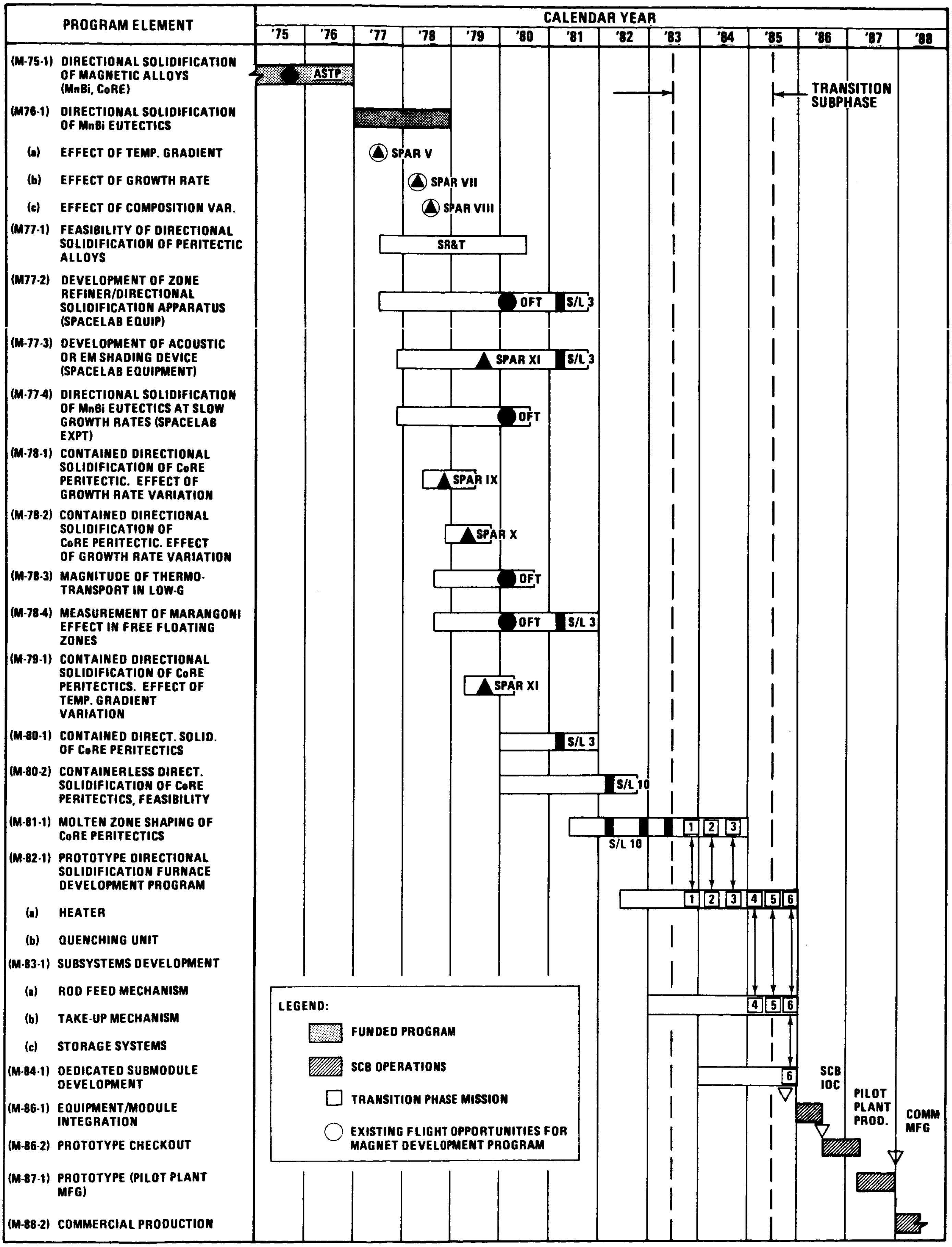
GRUMMAN



PROGRAM ELEMENT
CALENDAR YEAR
'75 '76 '77 '78 '79 '80 '81 '82 '83 '84 '85 '86 '87 '88
(M-75-1) DIRECTIONAL SOLIDIFICATION OF MAGNETIC ALLOYS (MnBi, CoRE)
ASTP
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(c) EFFECT OF COMPOSITION VAR.
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SR&T
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OFT
S/L 3
(M-77-3) DEVELOPMENT OF ACOUSTIC OR EM SHADING DEVICE (SPACELAB EQUIPMENT)
SPAR XI
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(M-77-4) DIRECTIONAL SOLIDIFICATION OF MnBi EUTECTICS AT SLOW GROWTH RATES (SPACELAB EXPT)
OFT
(M-78-1) CONTAINED DIRECTIONAL SOLIDIFICATION OF CoRE PERITECTIC. EFFECT OF GROWTH RATE VARIATION
SPAR IX
(M-78-2) CONTAINED DIRECTIONAL SOLIDIFICATION OF CoRE PERITECTIC. EFFECT OF GROWTH RATE VARIATION
SPAR X
(M-78-3) MAGNITUDE OF THERMO-TRANSPORT IN LOW-G
OFT
(M-78-4) MEASUREMENT OF MARANGONI EFFECT IN FREE FLOATING ZONES
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(M-79-1) CONTAINED DIRECTIONAL SOLIDIFICATION OF CoRE PERITECTICS. EFFECT OF TEMP. GRADIENT VARIATION
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R&D PROGRAM

(M-75-1) LOW-G SOLIDIFICATION OF MAGNETIC ALLOYS ON ASTP

Start Date:	3/74
Completion Date:	11/76
Test Vehicle:	ASTP
Flight Date(s):	7/75
Hardware:	Multipurpose Furnace
Estimated Cost:	110 K
Objective:	Demonstrate feasibility of improving magnetic properties of selected alloys by low-g solidification.
Description:	Simultaneous isothermal solidification of 50 Mn-50 Bi and directional solidification of (Co, Cu) Ce and MnBi/Bi. Intrinsic coercive strength improvements of nearly 100 percent were observed in the MnBi/Bi.

R&D PROGRAM

(M-76-1) DIRECTIONAL SOLIDIFICATION OF MnBi EUTECTICS

Start Date:	12/76
Completion Date:	12/78
Test Vehicle:	SPAR V, VII, VIII
Flight Date(s):	6/77, 2/78, 6/78
Hardware:	AAFE Directional Solidification Furnace
Estimated Cost:	165 K
Objective:	Verification and further understanding of ASTP results.
Description:	Systematic directional solidification experiments will be conducted to determine the effect of growth rate and temperature gradient variation of the microstructure and magnetic properties of eutectic MnBi/Bi. Off-eutectic solidification experiments will be conducted to increase the volume fraction of MnBi without altering the morphology.

R&D PROGRAM

(M-77-1) FEASIBILITY OF DIRECTIONAL SOLIDIFICATION OF PERITECTIC ALLOYS

Start Date:	6/77
Completion Date:	6/80
Test Vehicle:	Ground Base Experiments
Flight Date(s):	—
Hardware:	Zone Refiner
Estimated Cost:	350 K
Objective:	Determine the thermal and compositional parameters suitable for directional solidification of Cobalt/Rare Earth (CoRE) alloys
Description:	CoRE alloys typical of the compositions used for permanent magnets ($Co_{17}RE_2$, Co_8RE, Co_5RE) will be solidified using a range of growth rates and temperature gradients analytically predicted to produce aligned microstructures. Microstructural and magnetic measurements will be used to define the most suitable range of parameters for further low-g study.

(M-77-2) DEVELOPMENT OF ZONE REFINER/DIRECTIONAL SOLIDIFICATION APPARATUS

Start Date:	6/77
Completion Date:	Open (Hardware complete by 6/79)
Test Vehicle:	OFT, Spacelab
Flight Date(s):	2/80, 3/81, ...
Hardware:	Automated Zone Refiner/Directional Solidification Apparatus
Estimated Cost:	450 K (The total cost will be shared by other programs.)
Objective:	DDT&E and determination of operating characteristics for flight unit
Description:	A floating zone refiner using heat lamps or imaging techniques will be developed. Samples 10 to 50 cm long, 0.5 to 4 cm diameter should be accommodated. Zone motion from 1 to 50 cm/hr should be provided. Provisions for auxiliary cooling to produce temperature gradients from 25 to 250^{o}C/cm will be necessary as well as provision for running the entire experiment in inert atmospheres. Equipment will be used for other programs.

R&D PROGRAM

(M-77-3) DEVELOPMENT OF SHAPING DEVICE

Start Date:	10/77
Completion Date:	Open (Hardware complete by 8/80)
Test Vehicle:	SPAR XI, Spacelab
Flight Date(s):	8/79, 3/81, ...
Hardware:	Acoustic or Electromagnetic Shaping Device
Estimated Cost:	550 K (The total cost will be shared by other programs.)
Objective:	DDT&E and determination of operating characteristics for flight unit
Description:	A device to shape molten metals into regular cross sections (squares, rectangles, etc) overcoming surface tension will be required to reduce waste in many containerless processes. Ground-based feasibility studies should be used to determine whether acoustic or electromagnetic systems will be most suitable. Preliminary evaluation of the concept (s) will take place on SPAR XI. Equipment will be used for other programs.

R&D PROGRAM

(M-77-4) DIRECTIONAL SOLIDIFICATION OF MnBi EUTECTICS AT SLOW GROWTH RATES

Start Date:	10/77
Completion Date:	7/80
Test Vehicle:	OFT
Flight Date(s):	2/80
Hardware:	AAFE Directional Solidification Apparatus
Estimated Cost:	125 K
Objective:	Complete experiments on MnBi at slow growth rates
Description:	Experiments on the contained directional solidification of eutectic MnBi/Bi will be completed. This will involve slow rates of growth ($<$50 cm/hr). Microstructural and magnetic measurements will complete the analysis and permit comparison with theory.

R&D PROGRAM

(M-78-1) CONTAINED DIRECTIONAL SOLIDIFICATION OF CoRE PERITECTICS (COMPOSITION VARIATIONS)

Start Date:	5/78
Completion Date:	5/79
Test Vehicle:	SPAR IX
Flight Date(s):	11/78
Hardware:	AAFE Directional Solidification Apparatus (upgraded to reach 1600°C)
Estimated Cost:	75 K
Objective:	Evaluate the role of low-g on directional solidification of CoRE alloys of selected compositions.
Description:	Range of compositions found most suitable for directional solidification experiments (M-77-1) will be processed at fixed growth rates and temperature gradients. Microstructures and magnetic properties will be compared with identical materials whose properties had been optimized during the ground based tests.

(M-78-2) CONTAINED DIRECTIONAL SOLIDIFICATION OF CoRE PERITECTICS (GROWTH RATE VARIATION)

Start Date:	10/78
Completion Date:	10/79
Test Vehicle:	SPAR X
Flight Date(s):	3/79
Hardware:	AAFE Directional Solidification Apparatus (upgraded to reach 1600°C)
Estimated Cost:	75 K
Objective:	Evaluate the role of growth rate on the low-g directional solidification of CoRE peritectics
Description:	Using one or two of the compositions optimized from previous programs (M-77-1) and (M-78-1) directional solidification experiments will be carried out using fixed temperature gradients over a range of growth rates. The appropriate values for the growth rates will be determined by extensive ground based testing. Low-g samples will be compared with one-g samples for microstructure and magnetic properties.

(M-78-3) MEASUREMENT OF THERMOTRANSPORT DURING DIRECTIONAL SOLIDIFICATION

Start Date:	8/78
Completion Date:	8/80
Test Vehicle:	OFT
Flight Date(s):	2/80
Hardware:	Modified Directional Solidification Apparatus Developed for AAFE
Estimated Cost:	175 K
Objective:	Determine the impact of the significant reduction of convection level on thermotransport in high temperature gradients.
Description:	Using contained directional solidification techniques to minimize convective flow, an assessment will be made as to the level of enhancement of chemical thermotransport. Ground base analytical programs will anticipate the impact of laminar flow or creeping motion on the thermotransport and the resultant solidified composite. Hold and quench studies will detail segregation rates as a function of thermal gradient and geometry. Change of rate studies will identify steady impact of thermotransport on the directionally solidified composite.

(M-78-4) MEASUREMENT OF MARANGONI EFFECTS IN FREE FLOATING ZONES

Start Date:	8/78
Completion Date:	12/81
Test Vehicle:	OFT, S/L 3
Flight Date(s):	2/80, 3/81
Hardware:	Float Zone Directional Solidification Unit and Contained Directional Solidification Unit
Estimated Cost:	350 K
Objective:	Determine whether high thermal gradients and free liquid surfaces formed during floating zone directional solidification, will lead to appreciable convection due to Marangoni flow. Determine whether this will impact the solidified crystal.
Description:	Make comparative studies of the dopant distributions found in contained and uncontained melts of similar geometry, exposed to identical thermal profiles. Assessment of whether surface activation or reaction can impact the level of Marangoni convection and the resultant microchemical distribution. This would require the variation of the gaseous environment surrounding the floating zone. Variation of dopant level, zone geometry, and rotation would be areas for additional study. Identification of convective level will determine significance of thermotransport (M-78-3) and will define experimental requirements for M-80-1.

(M-79-1) CONTAINED DIRECTIONAL SOLIDIFICATION OF CoRE PERITECTICS (TEMPERATURE GRADIENT VARIATIONS)

Start Date:	3/79
Completion Date:	3/80
Test Vehicle:	SPAR XI
Flight Date(s):	8/79
Hardware:	AAFE Directional Solidification Apparatus (upgraded to reach 1600°C)
Estimated Cost:	75 K
Objective:	Evaluate the role of temperature gradient variations in the contained directional solidification of CoRE peritectics
Description:	In this final SPAR experiment, we will complete the parameter variation study on the low-g solidification of CoRE peritectics. Using the composition selected in earlier work and growth rates from (M-77-1) and (M-78-2) we will systematically vary the temperature gradient to optimize the metallurgical structure and magnetic properties.

(M-80-1) CONTAINED DIRECTIONAL SOLIDIFICATION OF CoRE PERITECTICS

Start Date:	5/80
Completion Date:	12/81
Test Vehicle:	Spacelab 3
Flight Date(s):	3/81
Hardware:	AAFE Directional Solidification Apparatus (upgraded to reach 1600^{o}C)
Estimated Cost:	125 K
Objective:	(1) Verify SPAR IX, X, XI results (2) Extend growth regime to much slower growth rates
Description:	Further evaluation of feasibility of directional solidification of CoRE peritectics by verification of earlier SPAR results (M-78-1, 2) and (M-79-1). Extension of these programs with lower growth rates (<50 cm/hr) on selected alloy compositions will be carried out. Most suitable range of parameters (compositions, temperature gradient, growth rate) will be selected for the containerless directional solidification experiments.

(M-80-2) FEASIBILITY OF CONTAINERLESS DIRECTIONAL SOLIDIFICATION OF CoRE PERITECTICS

Start Date:	1/80
Completion Date:	10/82
Test Vehicle:	S/L 10
Flight Date(s):	3/82
Hardware:	• Directional Solidification/Zone Refiner • CORE Unit • High Vacuum System • Inert Gas Purification System
Estimated Cost:	350 K
Objective:	Determine feasibility of containerless directional solidification of CoRE peritectic alloys
Description:	Using the inputs from the previous studies on the contained directional solidification of CoRE (ground based, SPAR and Spacelab 3) optimized alloy compositions and thermal parameters will be selected for evaluation of the feasibility of containerless directional solidification. Samples small enough to be water cooled to establish the desired temperature gradient will be used in conjunction with the zone refiner. The experiment will be carried out as a floating zone refining experiment.

(M-81-1) MOLTEN ZONE SHAPING OF ALLOYS

Start Date:	5/81
Completion Date:	12/84
Test Vehicle:	Spacelab, Transition Phase (1-3)
Flight Date(s)	3/82, 11/82, 5/8, 11/83, 4/84, 9/84
Hardware:	• Levitator (Type TBD) • Image Furnace • High Vacuum System • Inert Atmosphere Purification System • Shaping Unit
Estimated Cost:	750 K
Objective:	Establish feasibility of shaping molten metals without dies
Description:	Feasibility of shaping molten zones and maintaining their shape through the solidification step will be established. A suitable system, electromagnetic or acoustic will be selected. Evaluation of materials will begin with low melting pure metals and progress through low melting alloys, high melting metals and alloys and electronic materials. The role of the inert atmosphere will be assessed for acoustic devices. Experiments on Phase (4) and Phase (5) will concentrate on shaping CoRE peritectic alloys while they are being directionally solidified. Experiments on Phase (3), Phase (4) and Phase (5) will be carried out in conjunction with the prototype directional solidification furnace for the magnetic materials facility.

(M-82-1) PROTOTYPE DIRECTIONAL SOLIDIFICATION FURNACE DEVELOPMENT

Start Date:	5/82
Completion Date:	12/85
Test Vehicle:	Transition Phase 1-6
Flight Date(s):	11/83, 4/84, 9/84, 1/85, 5/85, 10/85
Hardware:	• Prototype DS Furnace • Shaping Device • Power Supply • Thermal Instrumentation • Gas Quenching Facility • Gas Tanks and Regulators • Vacuum System
Estimated Cost:	1.6M
Objective:	Demonstrate feasibility of containerless directional solidification of CoRE alloys using the prototype system
Description:	Based on ground based and space tests, a prototype directional solidification furnace, incorporating all the features required for magnet production will be designed, built and tested. Individual components will be initially checked out on the ground, delivered to space and rechecked in low-g. The complete unit will be assembled and run on Phase 5. The last three flight Phase (4,5,6) will be used to establish the optimum low-g operating conditions for the entire unit with CoRE alloys. Particular attention will be paid to the gas supply for the quenching facility.

(M-83-1) SUBSYSTEMS DEVELOPMENT

Start Date:	1/83
Completion Date:	12/85
Test Vehicle:	Transition Phase 4-6
Flight Date(s):	1/85, 5/85, 10/85
Hardware:	• Storage cans • Feed drive mechanism • Take-up Mechanism • Storage reel • Shape Monitor
Estimated Cost:	600K
Objective:	Demonstrate the feasibility, in space, of the mechanical part of the directional solidification process
Description:	Components to mechanically drive the CoRE rods through the directional solidification furnace will be designed, built and tested. Initial checkout will be on the ground, followed by testing in space. The entire mechanical system will be assembled and checked out by running rods through on a continuous basis.

R&D PROGRAM

(M-84-1) DEDICATED SUBMODULE DEVELOPMENT

Start Date:	1/84
Completion Date:	12/85
Test Vehicle:	Transition Phase 6
Flight Date(s):	10/85
Hardware:	• Submodule • SCB Support Subsystems
Estimated Cost:	Included in SCB
Objective:	Develop the dedicated submodule for the directional solidification of high coercive strength magnets.
Description:	DDT&E of the dedicated manufacturing submodule to accommodate the directional solidification process.

(M-86-1) EQUIPMENT MODULE INTEGRATION

Start Date: 1/86

Completion Date: 7/86

Test Vehicle: SCB

Flight Date(s): On SCB

Hardware:

- All hardware required for process
- Submodule
- SCB Support Subsystems
- Manufacturing Development Laboratory

Estimated Cost: 800 K

Objective: Integration of hardware and module for directional solidification process.

Description: Prototype hardware (furnace and subsystems) will be incorporated into the submodule on the ground. The entire system will be checked out functionally, then delivered to the SCB

(M-86-2) PROTOTYPE CHECKOUT

Start Date:	7/86
Completion Date:	3/87
Test Vehicle:	SCB
Flight Date(s):	On SCB
Hardware:	Prototype Mfg unit
Estimated Cost:	400 K
Objective:	Thorough checkout of operation of directional solidification apparatus.
Description:	The prototype manufacturing unit will be run with CoRE alloy rods to "fine tune" the operating characteristics of the facility. Operational parameters will be developed during this manual period of testing for use with the real-time process control computers. Small amounts of material (several hundred kilograms) will be produced and sold or given away to users' for their trials. Based on these results, final adjustment of the process will be made. Quality control procedures for checking the material produced on SCB will be developed using the prototype unit.

R&D PROGRAM

(M-87-1) PILOT PLANT MANUFACTURING

Start Date:	2/87
Completion Date:	12/87
Test Vehicle:	SCB
Flight Date(s)	On SCB
Hardware:	Prototype facility
Estimated Cost:	–
Objective:	Carry out pilot plant operations on SCB, manufacturing high coercive strength magnets.
Description:	Small quantities of material will be manufactured on a continuous basis. Material will be sold commercially to test the market. Orders will be taken for material to be produced during the commercial operation phase.

(M-88-2) COMMERCIAL PRODUCTION

Start Date:	1/88
Completion Date:	–
Test Vehicle:	SCB
Flight Date(s):	–
Hardware:	Prototype Facility
Estimated Cost:	–
Objective:	Commercial production of high coercive strength magnets
Description:	The facility will be run at a rate to supply the ground-based demand (initially estimated @ $\sim$10,000 Kg/yr). This will require the facility to run continuously (24 hr/day), all year. Resupply is presently estimated on a 30-day basis. If different alloy compositions or shapes are required, some time will be lost in the small modifications necessary to change the operating parameters.

MAGNETS/R&D FUNDING SCHEDULE